national accelerator laboratory

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ACCELERATOR EXPERIMENT: Main Ring Injection Mismatching of the Beam in the Transverse Phase Space

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It has been suspected for a long time that the operation of 8-GeV line is quite unsatisfactory as far as the matching of the beam shape is concerned. Before the last major shutdown in May, we tried to understand the optics of the line by deflecting the beam both horizontally and vertically and measuring the subsequent shifts of the beam position. The beam size was also measured at six positions for various quadrupole settings. One result of this trial was the discovery of a large beam distortion in the vertical direction due to the nonlinear field in the booster extraction septum magnet (MP01). Extensive analyses were carried out to find a satisfactory setting of quadrupoles but this was difficult because of the uncertainties in the calibration of each quadrupole. Also, there was only one wire scanner in the main ring (A13) so that it was not possible to find the degree of mismatching directly.

During the shutdown in May, three more scanners were installed (A10, A12 and A14) in the main ring and the thickness of the septum of MP01 was doubled in the hope that this would somehow reduce the beam distortion. On May 29, with the quadrupole setting that was believed to be the best, beam size was measured at six positions along the line as well as at four positions in the main ring. Data are still being analyzed and this is a partial result of the analysis. Hopefully, we may be able to find the optimum quadrupole setting by a series of such measurements and analyses but this will take time.

Quadrupole settings

power supply	shunt voltage (millivolts)	current (amp)
BQS	37.0	740

MRQS	36.4	728
MQ03	49.5	396
MQ12	47.0	94
MQ14	40.0	160
MQ41/42	16.6	33.2
MQ46	40.9	81.8

Data used

Horizontal and vertical beam size at A10, A12, A13 and A14. The full beam size is "defined" to be twice the FWHM. In the horizontal direction, the dispersion is simply subtracted from the beam size with $(\Delta p/p) = 0.1\%$ (total) and X_p given by SYNCH.

Procedures

Transformations of the beam shape are assumed to be given by SYNCH for $\nu_x = \nu_y = 19.4$ (supplied by W.W. Lee). There are three unknowns (two beam-shape parameters and the beam emittance) and four beam size data. Using the least-squares fit, we can find three unknowns.

Results

A. Horizontal

At A10, beam-shape parameters are:

$$\beta_x = 90.6 \text{ m}, \qquad \alpha_x = -1.043.$$

Ideal values are, from SYNCH,

$$\beta_x = 122.7 \text{ m}, \qquad \alpha_x = -1.2545.$$

The beam emittance is 1.02π mm-mrad. The dilution factor for the emittance due to mismatching is 1.39 so that the effective emittance of the beam in the main ring is 1.39×1.02 mm-mrad = 1.42π mm-mrad. The expected maximum beam size in the main ring is ±13.2 mm (plus dispersion). The fitting is as follows:

	measured beam size	calculated beam size
A10	± 9.6 mm	± 9.6
A12	5.7	6.0
A13	11.6	11.6
A14	5.5	5.8

B. Vertical

At A10, $\beta_y = 88.5$ m, $\alpha_y = 0.200$.

Ideal values from SYNCH are $\beta_y = 49.7$ m, $\alpha_y = 0.197$.

The beam emittance is 1.28π mm-mrad and the dilution factor of 1.80 gives the effective emittance 2.30π mm-mrad. The expected maximum beam size in the main ring is ±16.8 mm. This is certainly a very uncomfortable value.

	measured beam size	calculated beam size
A10	±11.1 mm	±10.6
A12	14.3	14.6
A13	7.9	6.1
A14	7.9	8.2

The fitting is not very good at A13 but the overall picture seems to be reasonable. In any case, it is quite obvious that we have to achieve a better matching in the vertical direction. The intensity of the beam was approximately 40 mA and the injection into the booster was single-turn. More information is available from R. Stiening and S. Ohnuma.

S. Ohnuma

Appendix

QUESTION

At two arbitrary points A and B in the main ring, matched beam-shape parameters are known from SYNCH:

$$\beta_A \text{ and } \alpha_A \text{ at A and } \beta_B \text{ and } \alpha_B \text{ at B.}$$

The 8-GeV line is always adjusted such that

$$(\text{beam size at B/beam size at A})^2 = \beta_B/\beta_A.$$

In addition to this condition, if we tune the line such that the beam size at A takes the minimum value, how good is the matching? Assume that we also know the phase advance ϕ from A to B.

ANSWER

The minimum beam size attainable at A corresponds to

$$\beta = \beta_A\,|\sin\phi| \quad \text{and} \quad \alpha = \alpha_A\,|\sin\phi| + \sin\phi\,\cos\phi/|\sin\phi|.$$

The dilution factor for emittance due to this mismatching is

$$|\tan(\phi/2)| \quad \text{or} \quad |\cot(\phi/2)|$$

whichever is larger than or equal to unity.

ϕ	dilution factor
90°	1.000
80	1.192
70	1.428
60	1.732

Starting from the above condition, one can make β equal to β_A since $\sin\phi$ is known. However, two solutions are possible for this.

1. perfect matching, $\beta = \beta_A$ and $\alpha = \alpha_A$.
2. $\beta = \beta_A$ but $\alpha = \alpha_A + 2\cot\phi$.

   In this case, the matching is worse. The dilution factor is

$$\tan^2 (\phi/2) \text{ or } \cot^2 (\phi/2)$$

whichever is larger than or equal to unity.

It is important to keep the ratio of the beam size always "correct". Also, $\sin\phi \neq 0$ is assumed. If $\sin\phi = 0$, the ratio of the beam size is always "correct" independent of tuning.